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3D-Printed Antennas for Satellite Communication

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Abstract: The design of dual band transmit arrays facilitates a decrease in the equipment used in satellite communications. Utilizing a single antenna for dual-band transmission and reception, rather of two antennas for each frequency, optimizes spatial efficiency and reduces equipment costs.

A novel design of a dual-band all-dielectric transmit array for 5G and satellite communications is introduced to facilitate a connection between ground and satellite terminals. This solution is designed for operation in the satellite Ka-band and is manufactured utilizing 3D printing technology. The objective is to get a High Gain above 35 dBi while ensuring a favorable Side Lobe Level, all at a minimal cost and with a straightforward method. The literature indicates that such designs have not yet been documented.

The distribution of a limited number of dielectric cells inside the transmit array seeks to minimize errors arising from the separate phase correction functions for each dual band. Two transmit arrays were constructed, and full-wave simulations were conducted to verify compliance with requirements. Results indicate a method that attains gains of 36.73 dBi at 20 GHz and 37.30 dBi at 30 GHz, while keeping the side lobe level at -19 dB. This design is compared to the single band performance at each frequency for the identical situation, resulting in a gain loss of 1.20 dBi at 20 GHz and 2.54 dBi at 30 GHz.

Keywords: *All-dielectric, ka-band, 3D-printing, transmit array, satellite communications, dual band*

Introduction

This chapter elucidates the background and purpose of the thesis. The first part delineates the motivations and aims that underpinned the development of this thesis. Subsequently, a synopsis of the current advancements in satellite communications and transmit arrays, along with other concepts pertinent to the construction of this thesis, will be presented. The final part addresses the primary problems associated with the whole procedure. In conclusion, the last part provides a summary of the thesis framework.

Motivation and Objectives 1.1

Globally, wireless communications have become a significant aspect of individuals' lives. Wireless communications, including mobile cellular networks, satellite communications, and broadcast radio, have facilitated the establishment of sustained interconnectedness among individuals and services inside society. The advancement of these technologies established more straightforward and efficient methods for disseminating information and data, rendering them essential in the emergence of new innovations.

The core premise of wireless communications is the transfer of data or information from one location to another using electromagnetic waves rather than cables or wires for the transmission process. The propagation of electromagnetic waves in free space enables a transmitter and receiver to communicate within a defined range based on their respective properties. With this notion in consideration, telecommunication businesses have significantly enlarged their networks over the years, enhancing the variety of wireless communications used and the quantity of components accessible for utilization. Satellite communications constitute a significant component of wireless communications, including a widespread distribution of equipment globally; they provide connection among users in the most remote regions.

Initially, military uses predominated the deployment and utility of satellite communications. Currently, satellite communications are essential for telecommunications applications, including television, telephone, radio broadcasting, and internet services, which depend on satellites for optimal functionality. The congestion of the Ku-band has led to the emergence of the Ka-band, and research into this higher frequency spectrum has shown advantages such as increased bandwidth,

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enhanced capacity, and more cost-effective antennas. 1 Recent research have focused on developing tiny, cost-effective antennas capable of producing high-gain beams, which are crucial for satellite communications owing to the significant distance between ground and satellite terminals. Aperture antennas are an advantageous approach for attaining large gains, having shown both cheap cost and simplicity. [2] [3]

An economical and straightforward method for executing this sort of connection is via the use of a transmit array. A transmit array enhances power radiation in desired directions while suppressing it in undesired ones. Typically, its design resembles a plate of defined thickness that, based on the arrangement of its constituent elements, directs an incoming beam onto a specified trajectory. In satellite communications, a high-gain controlled beam is essential due to the significant propagation loss across extensive distances, necessitating increased gains for both transmission and receiving.

Furthermore, the growing need for increasingly compact antenna designs makes a dual-band configuration quite attractive. Dual band denotes the two distinct frequencies at which the transmission array operates. By engineering a single transmit array capable of executing both uplink and downlink functions across distinct frequency bands, the necessary number of antennas for establishing a connection is halved.

Satellite communications

The growth of wireless communications has gained paramount significance throughout the years, with various applications and solutions being developed at an accelerated rate. To enhance and streamline communications globally, satellites have played a pivotal role in facilitating connections among individuals and services. Satellites are very advantageous for wireless communications due to their exceptional dependability and extensive range [4].

The function of satellites may be succinctly described as serving as a middleman between two entities. The satellite acquires a signal from a designated ground station at a specified frequency, amplifies it, and then transmits the signal to the target ground station at a different frequency. This approach facilitates a transparent internet connection between a terrestrial end user and an orbiting satellite.

Satellite communications will significantly enhance total communications by supplementing terrestrial networks to provide wider coverage to consumers. Research has linked the amalgamation of terrestrial and satellite systems for many applications, yielding technological advantages contingent upon the context [5]. The advent of 5G technology will render satellites crucial, since their integration with terrestrial cellular networks will provide a robust network that fosters the development of various services.

Satellites may be positioned in various flight routes, orbits, and orientations, which can be classified based on their use and geographic location. Generally, there are three categories of orbits distinguished by the altitude at which the satellite operates. Figure 1.1 illustrates the many classifications of satellite orbits.

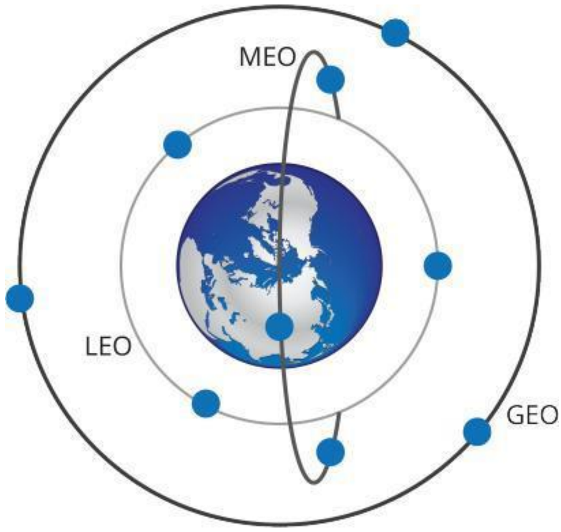
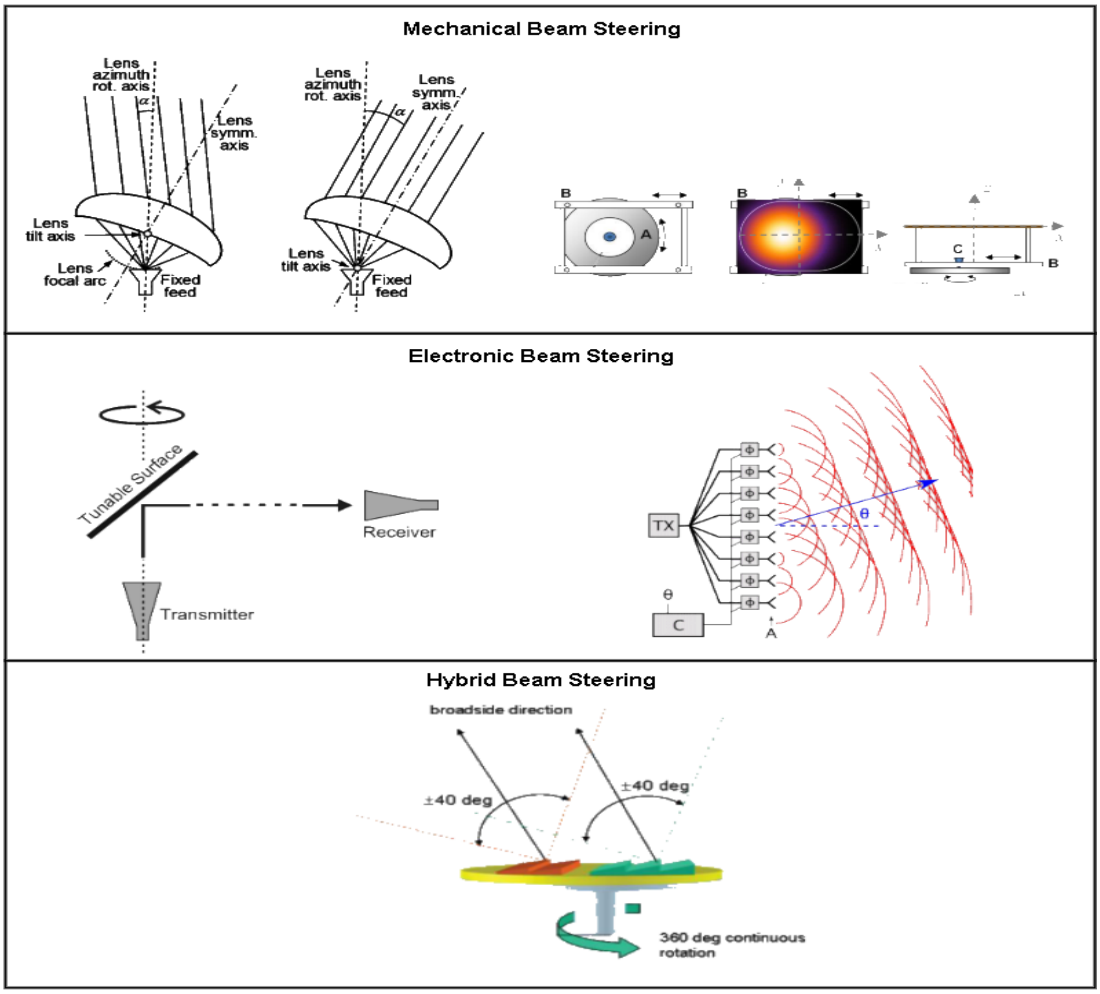


Figure 1: Different satellites orbits [7]

These orbits possess distinct traits and criteria, which are as follows:

Geostationary Orbit (GEO): The apex orbit, often about 36,000 kilometers above the equatorial plane, synchronizes with the Earth's rotation, rendering its location seemingly stationary to a fixed observer on the planet. As it occupies the highest orbit, it can provide the most extensive coverage with a less number of satellites. Consequently, it is an excellent option for telecommunications and meteorological applications. Moreover, due to its orbital duration, ground-based antennas can function well without the need to monitor the satellites' movement. Typically, three satellites suffice to adequately encompass the total surface area of the globe. These satellites are insufficient for mobile wireless broadband access applications because to the considerable distance and the elevated transmission power needed, which is incompatible with mobile terminals. The expense of launching a satellite into orbit is much more due to the considerably bigger distance it must traverse. 8

MEO: located between LEO and GEO, with an orbital period varying from 2 to 24 hours. The quantity of satellites necessary for complete Earth coverage is much more than that for the GEO orbit, but less than that for the LEO orbit. The predominant applications for this category are GPS, Galileo, and Glonass, which are satellite navigation constellations. These satellites need 5 continuous monitoring by terrestrial antennas or only a delay till the subsequent satellite is positioned above. MEO satellites provide a balance between the benefits and drawbacks of both GEO and LEO orbits.



Transmit arrays

This thesis focuses on the design and manufacturing of an all-dielectric dual-band transmit array for communication with a GEO satellite. To establish dependable communication with a satellite in a GEO orbit, an antenna must emit a high-gain and highly directed beam. To transmit or receive energy over long distances, it is essential to focus the energy toward the intended destination while minimizing dispersion in other directions. This paper focuses on transmit arrays and considers two kinds of solutions—transmissive and reflected arrays—to maximize directivity. To facilitate the adaptation of the geometry of these arrays for optimal collimation of the incident beam, they are segmented into smaller cells that may be built individually.

By partitioning the array into cells of predetermined dimensions, each cell may be meticulously designed to synchronize the phase of the diffracted/reflected wave, hence achieving high gain and minimizing side lobe levels that may interfere with the transmission of the target signal. The distinct properties of each cell at every place within the transmit array establish the geometry of the array.

The feed disseminates into the array, and by specifying its properties at each point in the array, the array converts the feed's radiation into a high-gain, controlled beam. The array's shape determines the desired direction of beam radiation while aiming to reduce radiation in all other directions. The change in cell characteristics will cause the radiating electromagnetic wave from the feed to undergo physical alterations, resulting in a high-gain beam capable of communicating with the satellite.

These physical alterations pertain to the phase of the wave that traverses the array. The feed emits a spherical wave towards the transmit array, which then alters the wavefront from the feed into a planar wavefront at its output, based on its geometry. A planar wavefront is advantageous for attaining a highly directional beam, since the communication involves a considerable distance.

Reflective and transmissive arrays may be differentiated by the physical phenomena that arise when the incident wave interacts with the array. The reflective array comprises a reflecting surface that reflects incoming energy to generate a unidirectional beam of radio waves by converting the wave front into a planar shape. Conversely, the transmit arrays let radiation to traverse the array, so allowing for the regulation of each cell's properties to produce a planar wave front at the output, facilitating long-distance communication. Figure 1.3 illustrates the operations and distinctions elucidated in the preceding remarks. A prevalent illustration of GEO applications is a parabolic antenna, whereby a feed, often a horn, emits signals to a reflector, the parabolic dish, enabling satellite communication. The parabolic reflector does not conform to any of these categories, since its components do not actively contribute to the output beam; the reflector only functions as a mirror.

Design Process

Numerous current tools and platforms enable the customization of mechanical structures; this idea is further developed in the RF domain via software that use high-level design parameters to generate circuits, simulate performance, and produce Computer Assisted Manufacturing (CAM) files. By astutely using this technique, the design may be easily modified or tailored after the original creation. A Computer Assisted Drafting (CAD) tool may further alter the structure to tailor the mechanical interface, while a machine toolpathing code (a slicer) is used to convert the CAM files into a format compatible with the printer. The monopole array, equipped with an integrated beamforming network and radome, is used to demonstrate the methodology applied to each component shown. Design Instrument: A bespoke frequency-domain circuit simulation algorithm has been created that utilizes a schematic input (Figure 1) to represent a circuit's S-Parameters.

The design tool manages variables, does computations, and conducts optimizations; the results represented for the monopole array are shown (Figure 2). The tool can autonomously produce the layout from the schematic and generate Stereo-lithography (STL) files for both metal and plastic materials. The design process is greatly streamlined since the single schematic/tool models the device and generates all CAM files, eliminating the need for a CAD-specific tool like SolidWorks.

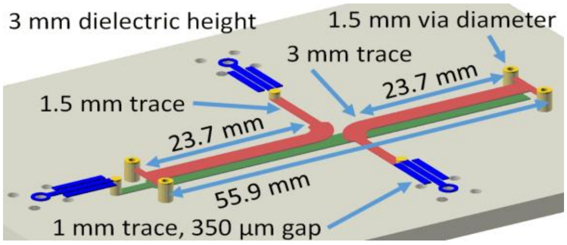


Figure 2: CAD view of a stripline Marchand balun with two stripline inner layers (green and red) and a top layer coplanar waveguide section (blue).

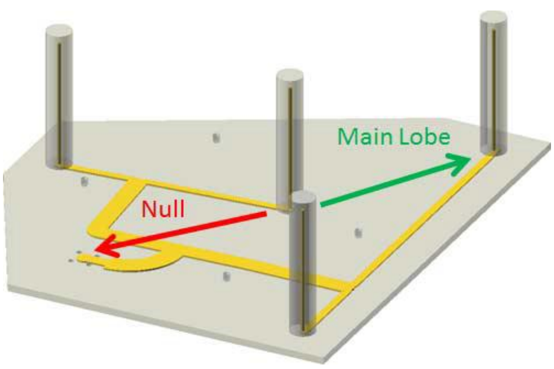


Figure 3: CAD view of a four-monopole array with an integrated stripline beamforming network.

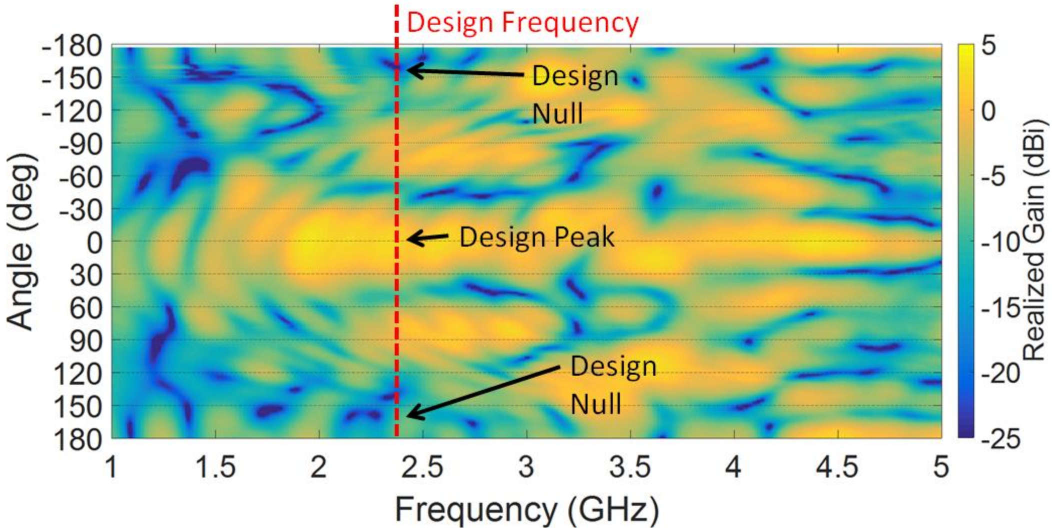


Figure 4: Measured gain pattern over frequency and angle.

Conclusions and Future Work

To diminish the geometric complexity and overall expense of existing solutions in the literature for communication with GEO satellites, an all-dielectric transmit array including 64 designed unit cells was developed. Furthermore, the capability to transmit and receive across two separate frequency bands results in a reduction in the number of antenna components required for communication between ground and satellite terminals. The challenge of the dual-band situation lies in the required separate phase wrapping at each band, which may result in a substantial number of phase pair possibilities at both frequencies. Utilizing a limited number of dielectric cells results in the unavailability of all requisite phase pairs; yet, the cells may be arranged to minimize the error over the whole transmit array. Moreover, the dielectric suitable for the laboratory's 3D printer was PLA, which is characterized by significant transmission losses. A potential use for these arrays would include substituting parabolic reflector antennas atop rooftops. The transmit array would provide a cost-effective and visually appealing alternative to current antennas.

Two transmit arrays with distinct focal distance configurations were simulated using full-wave simulations in CST. The outcomes derived from both transmit arrays adhered to the parameters established at the outset of this study, attaining a gain above 35 dB at both frequencies, together with a very low side lobe level of sub -19 dB. Among the two transmit arrays, the superior performing one was selected for the 71.

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